# IPHWG Task 2 Report for TAEIG

## REPORT OBJECTIVE

This report is submitted in response to an action item from the March, 2000, TAEIG meeting, as follows:

> Ice Protection HWG to prepare report on Task 2 status, lack of information available, funding, etc., and what needs to be done before they can finish the task. They are to make a recommendation to TAEIG for future plan on tasking.

## TASK STATEMENT

Task 2 of the IPHWG is as follows:

> Review National Transportation Safety Board recommendations A-96-54, A-96-56, and A-96-58, and advances in ice protection state-of-the-art. In light of this review, define an icing environment that includes supercooled large droplets (SLD), and devise requirements to assess the ability of aircraft to safely operate either for the period of time to exit or to operate without restriction in SLD aloft, in SLD at or near the surface, and in mixed-phase conditions if such conditions are determined to be more hazardous than the liquid phase icing environment containing supercooled water droplets. Consider the effects of icing requirement changes on 14 CFR Part 23 and Part 25 and revise the regulations if necessary. In addition, consider the need for a regulation that requires installation of a means to discriminate between conditions within and outside the certification envelope.

For clarity, this task is subdivided into its parts, as follows, and then each is considered separately. References to FAR Part 23 are also removed per recent TAEIG action.

> **2a**. Review National Transportation Safety Board recommendations A-96-54, A-96-56, and A-96-58, and advances in ice protection state-of-the-art.
>
> **2b**. Define an icing environment that includes supercooled large droplets (SLD).



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**2c**. Devise requirements to assess the ability of aircraft to safely operate either

- **i)** for the period of time to exit, or
- **ii)** to operate without restriction

in SLD aloft and at or near the surface.

**2d**. Devise requirements to assess the ability of aircraft to safely operate either

- **i)** for the period of time to exit, or
- **ii)** to operate without restriction

in mixed-phase conditions if such conditions are determined to be more hazardous than the liquid phase icing environment containing supercooled water droplets.

**2e**. Consider the effects of icing requirement changes on 14 CFR Part 25 and revise the regulations if necessary.

**2f**. Consider the need for a regulation that requires installation of a means to discriminate between conditions within and outside the certification envelope.

## COMPLETED PARTS OF THE TASK

**Task 2a** is complete, except that the review of advances in ice protection state-of-the-art may be considered on-going if and as new developments emerge.

**Task 2d** may also be considered technically complete. Mixed-phase conditions were first discussed in detail at the 3rd IPHWG meeting in July, 1998. The sense of the group at this meeting was that mixed-phase icing is a common occurrence and probably existed during many icing tests but was not recognized as such because the instrumentation was not capable of detecting the solid-phase content until now. Recent measurements in Europe and North America have shown that a large percentage of clouds examined for SLD conditions contained ice crystals (over 40 percent in the Great Lakes area).

An FAA-sponsored 1964 report by D. T. Bowden and others, Engineering Summary of Airframe Icing Technical Data, Technical Report ADS-4, stated that flight through clouds of ice crystals, snow, or mixtures of ice crystals and liquid water is not uncommon. The report further commented that normally the aircraft ice protection system should not be turned on since the airframe and engine surfaces will remain clean; however, in "mixed" cloud conditions, ice may accumulate and require use of the ice protection equipment. The capacity of thermal systems may be exceeded and it may be necessary to escape the icing conditions as rapidly as possible. It has been speculated that reports of excessive icing might be the result of flight in mixed clouds with anti-icing systems overtaxed by the increased heat needed first to melt the ice crystals, then to warm and evaporate the water. However, documented evidence of severe airframe icing problems in clouds of ice crystals or mixed clouds is lacking. (The Report does reference a World Meteorological Organization Report by R.F. Jones, Ice Formation on Aircraft, WMO-No. 109, TO 47.) As long as the engine(s) continue to deliver the required thrust, operation in ice crystals is not likely to present severe problems.

The FAA Specialists Workshop on Mixed-Phase and Glaciated Icing Conditions was held in Atlantic City on December 2-3, 1998 — 34 years after the ADS-4 report. A report on the results of the Workshop was presented by the FAA Technical Center and discussed at the 9th IPHWG meeting in September, 1999. Existing JAA and UK requirements for consideration of mixed-phase icing were also presented and discussed. It was noted that these requirements generally refer to powerplant/engine installations, not to aerodynamic surfaces.

The FAA presentation to the IPHWG noted that the consensus among icing engineers and scientists dating back to the 1950's has been that airframe icing in mixed-phase conditions is not more hazardous than airframe icing in purely liquid water conditions, which are equivalent (in terms of total water content and collection efficiency) except for the absence of the ice crystals. The limited amount of relevant information in the public literature supports this consensus. Discussion at the FAA Specialists Workshop made it clear that it would be very difficult and expensive to design a study to fully address this issue, and there are no current plans for such an effort. Furthermore, by its very nature, it is extremely difficult to obtain operational data that bears upon the question of airframe icing in mixed-phase conditions; a pilot would not ordinarily be able to distinguish between mixed-phase and purely liquid conditions, nor would airframe ice accretions ordinarily permit this distinction to be made after the aircraft reached the ground. The FAA presentation concluded that, "the public literature does not provide evidence of mixed-phase environments that are more hazardous than comparable environments containing supercooled drops only."

However, a paper presented by Dr. Kamel Al-Khalil at the Workshop, Effect of Mixed Icing Conditions on Thermal Ice Protection Systems, concluded in part, ". . . that evaporative thermal [ice protection] systems are not significantly affected by the state of the water content [liquid or ice water content] but rather by its total content [liquid plus ice water content] in the atmosphere." The analytical work of Dr. Al-Khalil determined that running-wet thermal systems are significantly affected by the high ice content. This is typical of engine inlet ducts (e.g., helicopters and turboprop) and environmental control system scoops, especially where near-stagnant regions may exist.

Dr. Al-Khalil also made a presentation on this subject at the 13th IPHWG meeting. Subsequent to the presentation, the following points were discussed by the group:

- There is no data as to how the collection efficiency changes as the cloud changes phase from liquid to mixed to glaciated. Most comparisons conservatively assume that it remains the same.
- JAA has standards for mixed-phase environments which are applicable to powerplant/engine installations and pitot tubes, for which there are no equivalent FAA standards.
- There have been cases of ice concentration issues associated with the accretion of ice crystals in complex geometric configurations, such as some engine inlet ducts.
- Running-wet systems which vary power input to maintain a constant surface temperature behave differently than those which maintain a power input which is either constant or a function of engine power. Running-wet systems designed to the cold temperature extremes of Appendix C are less effected by ice crystals at a constant collection efficiency. The area of significant concern is for running-wet thermal ice protection systems whose design point is marginal relative to the freezing point.

This information examined by the IPHWG does not provide a compelling argument that these conditions are more hazardous than the liquid-phase icing environment. However, further examination of existing unpublished studies that address mixed-phase icing conditions and research on empirical work to clarify the effects of mixed-phase icing conditions on thermal anti-icing energy requirements appear warranted. This further work can be accomplished independently in parallel to IPHWG efforts to address defining the SLD icing environment.

Furthermore, there is some proprietary evidence that such environments may sometimes be hazardous because of their effects on engine installations and probes in certain designs. JAA and FAA practices with regard to engine installations and probes are not in harmony with respect to mixed-phase and glaciated conditions. Since power-plants/engines and their installations are not within the purview of the IPHWG, it is recommended that the ARAC leadership consider whether another ARAC Working Group should be tasked to seek out, examine, and evaluate such evidence.

## REMAINING PARTS OF THE TASK

**2b**. Define an icing environment that includes supercooled large droplets (SLD).

and

**2c**. Devise requirements to assess the ability of aircraft to safely operate either

i) for the period of time to exit, or
ii) to operate without restriction

in SLD aloft and at or near the surface.

As briefed and agreed at the April, 1998, TAEIG meeting, "define an icing environment" (Task 2b) does not mean "revise Appendix C." A proposal for revision of Appendix C is FAA Icing Plan Task 9, scheduled for June, 2003 (attached as Appendix 1 for convenience). However, it was also stated that as IPHWG Task 2b was completed, the quality of the icing environment defined would nonetheless be evaluated to determine if it was adequate to propose new certification standards to replace or supplement Appendix C.

A master SLD database is being prepared by Dr. Richard Jeck of the FAA Technical Center. The table below lists the SLD flights that are contained in the Master Database as of December, 2000.

**Flights Included in the Master SLD Database as of December 31, 2000**

| PROJECT | LOCATION | AGENCY | FLIGHTS | DATA MILES | SLD TYPE |
|---|---|---|---|---|---|
| SCPP (1985) | California | U. Wyoming | 3 | 148 | ZL |
| UND/FAA(1990) | Kansas City | U. North Dakota | 3 | 350 | ZR |
| WISP (1994) | Colorado | NCAR/U.Wyoming | 3 | 419 | ZL |
| NASA/FAA/ NCAR SLD (1997-98) | Great Lakes | NASA/GRC | 13 | 722 | ZL & ZR |
| Canadian CFDE-1 (1995) | Newfoundland | AES | 1 | 273 | ZL |
| Canadian CFDE-3 (1997) | So. Ontario | AES | 1 | 81 | ZL |
| | | | | 1,993 nmi | |

With 9 more cases from past Canadian flights added in January and February, 2001, there remain about 36 more flights from 7 projects to be added to the database. This will ultimately take several years to complete. In order to avoid delaying Task 2 that long, the IPHWG decided last year that the addition of an adequate amount of data from the most readily available and reliable sources should provide an interim database sufficient for Task 2 purposes. About 56 SLD flights from NASA and Canadian SLD research flights from 1995 to 1998 were anticipated. These data were collected using the same types of research equipment and were processed using the same, well-understood procedures, so their validity for the database would not be in question. It turned out however, that only 24 of the available 56 flights had sufficient SLD content to merit inclusion in the Master SLD database. Nevertheless, with more than 2,000 nmi of select quality SLD data now in the Master SLD Database at the FAA Technical Center, the IPHWG is satisfied that this is sufficient for Task 2 deliberations to proceed.

The eventual addition of the remaining flight data is not expected to substantially change the results or conclusions derived from the interim database. Therefore, the interim database as of February 28, 2001, could be regarded as the completion of one aspect of Task 2b and is understood to not be a revision Appendix C.

It is determined that the SLD icing environment as defined by the completed database will be adequate for proposing certification standards to supplement Appendix C. Preparation of proposed SLD-inclusive revisions to Appendix C, under Task 2b, and the development of requirements for assessing operational safety during flight in SLD conditions, per Task 2c, are discussed below.

The IPHWG member organizations have done a great deal of work with the partial SLD database which presently exists to understand what is involved in completing Tasks 2b and 2c. Various statistics have been compiled from the data. Several relevant papers have been published in the open literature (see Appendix 2 for references). Calculation of ice shapes using existing icing codes, such as LEWICE, has been done to investigate the suitability of these codes in conjunction with SLD. These investigations have resulted in the following conclusions:

**(1)** Given an engineering standard, the requirements for accomplishing Task 2c are essentially contained in the proposals that have been submitted by the Flight Test Harmonization Working Group (FTHWG). Such an engineering standard, at least an interim standard, can be developed by the IPHWG from the information compiled under Task 2b. A proposal for inclusion of this engineering standard in FAR Part 25 Appendix C will be made by the IPHWG under Task 2b.

There remains the issue of means of compliance with these new standards. The engineering tools do not presently exist at current certification confidence levels to get from a certification standard specifying an SLD environment (or environments) to the ice shapes that would be necessary to determine whether a given airplane would be able to operate under these conditions or would have to exit.

Completion of Task 2c requires the capability to determine the properties of ice accretions on airframe components resulting from SLD encounters, particularly their shape, location, and extent. The effects of these accretions on the airplane stall speeds, handling qualities, and performance can then be determined.

(2) Although a definition of SLD exists, it is neither useful nor meaningful in characterizing SLD environments. The existing definition was arrived at during the FAA International Conference on Aircraft Inflight Icing in May, 1996, and merely defines SLD as any droplet larger than 50 microns diameter. However, the current FAR Part 25 Appendix C envelopes specify median volume diameters (not maximum diameters) up to 50 microns. Droplets larger than 50 microns therefore are already required by the present rule in order to achieve 50 micron MVDs. Under the current requirements, use of a Langmuir E spectrum with a 50 micron MVD results in the presence of drops of up to 135 microns diameter. In the research flight data analyzed to date, which was strongly biased toward large drops by deliberately seeking such conditions, more than half of the encounters have MVDs within the existing Appendix C envelopes despite the presence of much larger drops.

The SAE paper cited in Appendix 2 as Reference No. 1 addresses these issues. However, it does not address horizontal extent, vertical extent, nor duration of the conditions. FAA Technical Center research has revealed that there is no consensus on the meaning of the term "horizontal extent" and, depending on its definition, it may be nearly impossible to measure. No definition of horizontal extent has been found anywhere in the icing literature. It will be necessary to address extent and duration in development of new certification standards.

(3) Development of candidate icing envelopes that include SLD requires that all of the above shortcomings of the current icing environment definitions be addressed. In addition, it requires consideration of what may constitute the most critical conditions. At this point, it is doubtful if anyone can say what a most critical condition is when related to airplane design; for example, is it high liquid water content with moderate-size drops, or low liquid water content but mostly in very large drops, or a lengthy case with large drops but low liquid water content, or something else? It is also necessary to consider whether any SLD condition which may be defined can be applied in isolation or whether it needs to be considered simultaneously with conventional Appendix C conditions. Critical conditions may also well turn out to be airplane specific and therefore variable.

**(4)** The existing computer codes are not presently adapted for generation of large-drop ice shapes. Shortcomings to the current methods when applied to SLD include:

- Droplet Thermodynamics
- Droplet breakup
- Droplet drag
- Gravitational Effects
- Splash
- Ice shape growth aft of the protected areas

The codes will need to be revised and validated to address these issues.

**(5)** Adequate representations of SLD conditions in icing research tunnels do not presently exist, in part due to lack of definition of these conditions and in part due to limitations of the current water-spray systems.

NASA has provided a road map of actions required to address these short-comings, pertinent pages of which are attached as Appendix 3. Some actions have already been taken. A meeting of a sub-group of the IPHWG was held at NASA Glenn Research Center in March, 2000, during which these matters were discussed and clarified. An outcome of the meeting was the selection of several representative flight data sets from the research flights for use during the recalibration of the Icing Research Tunnel currently in progress. It is not expected that the tunnel will be able to reproduce these conditions; rather, it is expected that the use of these conditions as models will allow the tunnel to generate conditions which can then be used to validate computer codes in the general physical conditions of interest. Once in hand, the codes can be used to calculate ice accretions for any SLD condition specified.

No technical breakthroughs appear to be required to do this work. The recalibration of the Tunnel is funded and in progress. Funding and resources are available to do work which will be required to complete Tasks 2b and 2c. Specific tasks have been defined, with scheduled activities to address current tunnel and code SLD limitations. NASA expects the work to take approximately 2 to 3 years to address many of the issues cited above.

**2e**. Consider the effects of icing requirement changes on 14 CFR part 25 and revise the regulations if necessary.

This task is applicable to determining whether other changes to 14 CFR Part 25 are needed as a result of the new SLD certification requirements developed under Tasks 2b and 2c. Task 2e cannot be undertaken until any revision of requirements is at least drafted under Tasks 2b and 2c.

> **2f.** Consider the need for a regulation that requires installation of a means to discriminate between conditions within and outside the certification envelope.

This part of Task 2 depends on two considerations. The first is need, which depends on whether there is evidence that some cliff exists at the edges of the current or any future (to be defined) certification envelopes that will endanger an airplane. The second consideration is whether there exists an operationally feasible technology to accomplish this objective. A technology has been identified which may be capable of detecting the presence of drops above a specified size; however, no mature products exist.

Understanding these issues depends on the other parts of Task 2, particularly 2b and 2c, as detailed above.

## CONCLUSIONS AND RECOMMENDATIONS

**Task 2a**: Complete; no recommendations.

**Task 2b:** The FAA Technical Center SLD database is considered sufficiently complete as of February, 2001, to proceed with the task. It is recommended that the IPHWG proceed with the development of at least interim SLD certification standards using the information from the database. The expected product may not, and should not (per FAA Icing Plan Task 9), be a complete revision of the Appendix C envelopes but should be sufficient to permit the generation of ice shapes for use in Task 2c. The group feels that these interim standards could be completed to the point of concept approval during the first quarter of 2002.

**Task 2c**: As discussed above, completion of this task is dependent upon the development of SLD certification standards under Task 2b and, possibly (see below), upon the availability of acceptable engineering tools to demonstrate compliance. Preliminary capability for simulating large-droplet conditions exists but it is rudimentary and not validated. Therefore, it is recommended that NASA and the FAA, in collaboration with international partners and private industry, pursue sources of funding to adapt codes, tunnels, and tankers to supply manufacturers and regulatory authorities with validated tools. These recommendations are consistent with Task 11c of the April, 1997, FAA In-flight Icing Plan (attached as Appendix 4 for convenience). These activities should be carried on concurrently with the IPHWG work on Task 2b. The recommendations from Icing Plan Task 11c and resulting activities should be targeted to support the completion of IPHWG Task 2c.

**Task 2d**: With respect to airplane handling and performance, the IPHWG has not found evidence that mixed-phase conditions are more hazardous than the liquid-phase icing environment containing supercooled water droplets having the same total water content. No further work should be scheduled on this subject in the IPHWG. The group may revisit mixed-phase conditions in Tasks 5 and 6.

JAA and FAA practices with regard to engine installations and probes are not in harmony with respect to mixed-phase and glaciated conditions. Since power-plants/engines and their installations are not within the purview of the IPHWG, it is recommended that the ARAC leadership consider whether another ARAC Working Group should be tasked to seek out, examine, and evaluate such evidence.

**Task 2e**: It is recommended that the IPHWG proceed with Task 2e following development of Tasks 2b and 2c to a point sufficient to understand what is required under Task 2e.

**Task 2f**: Understanding the issues of this task depends on the other parts of Task 2, particularly 2b and 2c, as detailed above. No recommendations can be made to TAEIG at this time.

In summary, the various elements of Task 2 can be accomplished without requiring any technical breakthroughs. A master SLD database will soon be available from the FAA Technical Center that will permit the definition of an icing environment. Engineering standards can then be derived from this icing environment. Given these engineering standards, the FTHWG's proposed in-flight icing certification rules will provide requirements to assess the ability of aircraft to operate safely.

The major difficulty will be defining acceptable means of compliance with the requirements. This issue has been discussed in detail within this document relative to Task 2c. The engineering tools do not presently exist at current certification confidence levels to get from a certification standard specifying an SLD environment (or environments) to the ice shapes that would be necessary to determine whether a given airplane would be able to operate under these conditions or would have to exit.

The majority of the group feels that the issuance of a final rule will be dependent upon the availability of acceptable means of compliance and that guidance material cannot be written until these means of compliance have been established. The FAA and ALPA, however, believe that completion of the final rule should not be contingent upon completion of the tool-development process described in the section of this report entitled, "Remaining Parts of the Task." They maintain that such a precondition is neither necessary nor prudent. Their position is based on both historical and current practices for icing certification. When the ice protection regulation, 14 CFR Part 25.1419, was issued in 1965, the capabilities for simulating icing conditions in laboratories and in flight, as well as the analyses used to predict ice shapes, were rudimentary or did not exist; thus, reliance was placed upon conservative use of then-existing icing simulation methods, engineering judgement, and flight testing in natural icing conditions to demonstrate compliance with icing requirements. Over time, engineering tools used to simulate icing conditions and predict ice shapes have improved and permitted a reduction in the amount of costly and time-consuming flight testing in natural icing conditions. Nevertheless, the engineering tools currently in use have not been fully validated by quantitative means. Current ice protection system certification practices permit use of the engineering tools based on engineering judgment, using the tools in a conservative manner, and qualitative verification of the tools during flight in measured natural icing conditions. The FAA believes that a similar means of compliance for SLD icing conditions could be developed that utilizes existing tools in combination with engineering judgment and conservative assumptions. The NASA representative believes that substantial improvements in the engineering tools will be seen within the next two years. It is NASA's opinion that the current tunnel, tanker, and code capabilities do provide a limited but, if properly used, conservative measure of ice shape characterization and performance for SLD conditions. NASA believes that these engineering tools, along with other design experience, can supply interim capability to address SLD certification issues. The group will continue to work Task 2 and attempt to resolve these differences to consensus as quickly as possible.

# Appendix 1

# FAA Aircraft Inflight Icing Plan, Task 9

**Task 9. The FAA, in concert with airworthiness authorities throughout the world, will consider a comprehensive redefinition of certification envelopes (such as those that appear currently in Appendix C) for the global atmospheric icing environment when sufficient information is available worldwide on SLD, mixed phase conditions, and other icing conditions, and when adequate simulation tools are available to simulate and/or model these conditions.**

**PLAN DETAILS, TASK 9:**

The lack of information to support a comprehensive redefinition of certification envelopes for the global atmospheric icing environment was emphasized by numerous participants at the May 1996 FAA-sponsored International Conference on Aircraft Inflight Icing. Additionally, as the number of aircraft increase, the probability of encountering intense icing conditions that were previously considered rare increases. As available icing cloud information and technologies improve, the FAA will consider a comprehensive change to the icing certification envelopes. This task is extremely complex--it requires information from around the globe and cooperation of aviation authorities around the world. In the interim, the FAA will work with ARAC to improve the safety of airplanes exposed to icing conditions that exceed the current Appendix C icing envelopes (see task 5 of this plan).

**Responsible Party:** FAA Icing Steering Committee.

**Schedule:**

June 2003: If appropriate, the FAA will propose a change to the envelope.

# Appendix 2

## References of SLD Literature

1. Shah, Patnoe, and Berg (The Boeing Company). Engineering Analysis of the Atmospheric Icing Environment Including Large Droplet Conditions. SAE Technical Paper 2000-01-2115.

2. Addy, H.E., D.R. Miller, and R.F. Ide. A Study of Large Droplet Ice Accretions in the NASA-Lewis IRT at Near-Freezing Conditions; Part 2. NASA TM-107424, 1998.

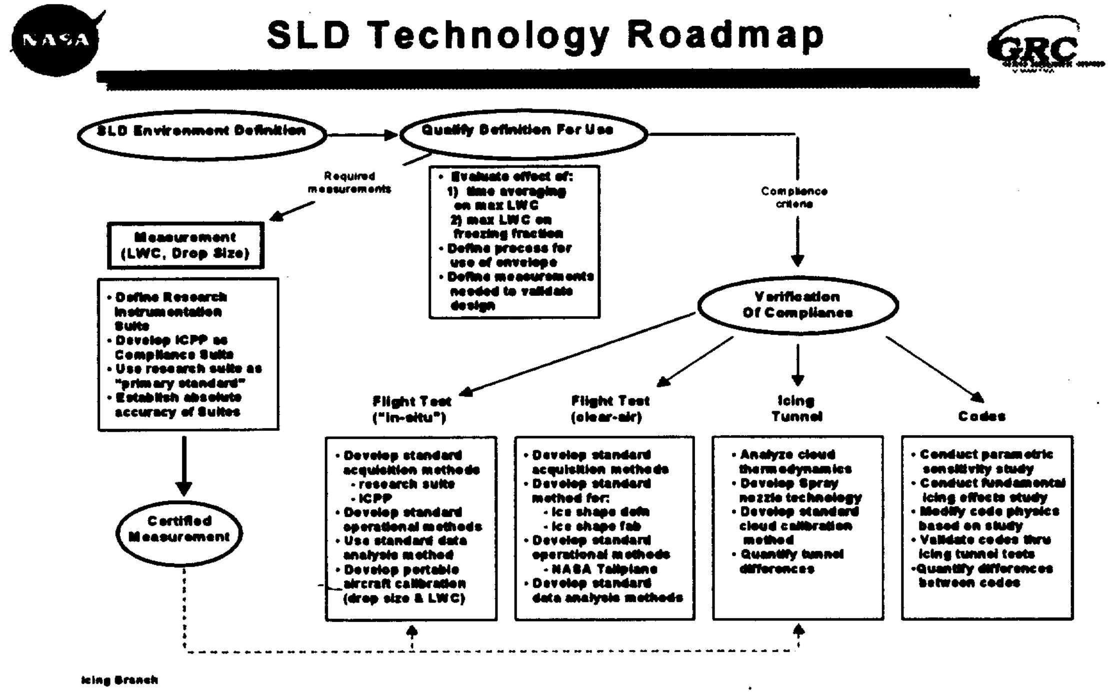
3. Miller, D.R., T.P. Ratvasky, B.C. Bernstein, F. McDonough, and J.W. Strapp. NASA/FAA/NCAR Supercooled Large Droplet Icing Flight Research: Summary of Winter 96-97 Flight Operations. NASA TM 1998-206620, AIAA-98-0577, 1998.

4. Wright, W.B. and M.G. Potapczuk. Computational Simulation of Large Droplet Icing. Cleveland: NASA Contractor Report, NASA Glenn Research Center, 1998. 11pp.

5. Cober, S.G. and G.A. Isaac. Characterizations of Aircraft Icing Environments that Include Supercooled Large Drops. Submitted to J. Appl. Meteor., 2000.

6. Isaac, G.A., S.G. Cober, A.V. Korolev, J.W. Strapp, A. Tremblay, and D.L. Marcotte. Canadian Freezing Drizzle Experiment. 37th Aerospace Sci. Meeting, 11-14 January. Reno: 1999.

# Appendix 3


SLD Technology Roadmap
SLD Environment Definition
Qualify Definition For Use
Required measurements
Compliance criteria
Measurement (LWC, Drop Size)
• Define Research Instrumentation Suite
• Develop ICPP as Compliance Suite
• Use research suite as "primary standard"
• Establish absolute accuracy of Suites
• Evaluate effect of: 1) time averaging on max LWC 2) max LWC on freezing fraction
• Define process for use of envelope
• Define measurements needed to validate design
Verification Of Compliance
Certified Measurement
Flight Test ("in-situ")
Flight Test (clear-air)
Icing Tunnel
Codes
• Develop standard acquisition methods - research suite - ICPP
• Develop standard operational methods
• Use standard data analysis method
• Develop portable aircraft calibration (drop size & LWC)
• Develop standard acquisition methods
• Develop standard method for: - ice shape defn - ice shape fab
• Develop standard operational methods - NASA Tailplane
• Develop standard data analysis methods
• Analyze cloud thermodynamics
• Develop Spray nozzle technology
• Develop standard cloud calibration method
• Quantify tunnel differences
• Conduct parametric sensitivity study
• Conduct fundamental icing effects study
• Modify code physics based on study
• Validate codes thru icing tunnel tests
• Quantify differences between codes
Icing Branch

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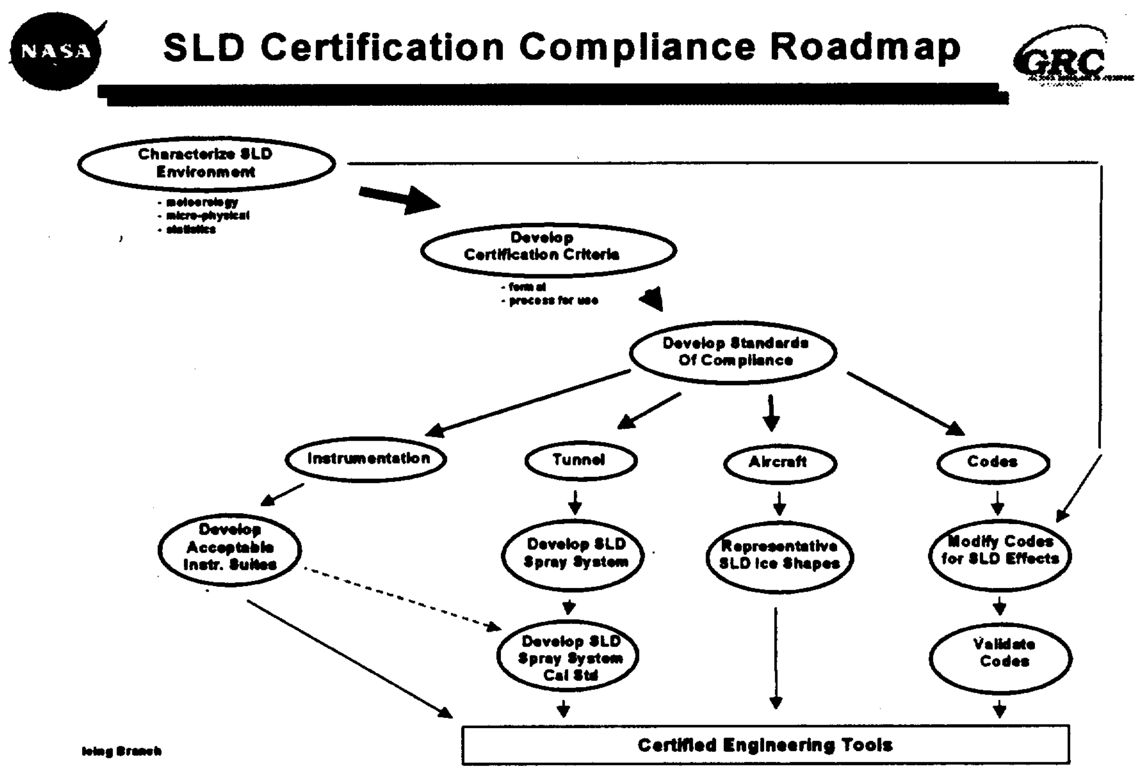
SLD Certification Compliance Roadmap
Characterize SLD Environment
- meteorology
- micro-physical
- statistics
Develop Certification Criteria
- format
- process for use
Develop Standards Of Compliance
Instrumentation
Tunnel
Aircraft
Codes
Develop Acceptable Instr. Suites
Develop SLD Spray System
Representative SLD Ice Shapes
Modify Codes for SLD Effects
Develop SLD Spray System Cal Std
Validate Codes
Certified Engineering Tools
Icing Branch

# Appendix 4

## FAA Aircraft Inflight Icing Plan, Task 11

**<u>Task 11</u>. Develop validation criteria and data for simulation methods used to determine ice shapes on aircraft, including icing tunnel, ice accretion computer codes, and icing tankers.**

**A. *VALIDATION REQUIREMENTS.* A working group will be formed to identify validation requirements for icing facilities (tunnels and tankers), and droplet impingement and ice accretion computer codes. The validation requirements will be appropriate for use in certification. The working group will develop information describing validation criteria (including specification of limitations) for icing simulation facilities, including instrumentation and data processing methodologies as they relate to facility calibrations, and for impingement and ice accretion codes. This will be a coordinated effort among research organizations, industry, and regulatory authorities. This material will be evaluated by the FAA for adoption as guidance material.**

**<u>PLAN DETAILS, TASK 11.A.</u>:**

The working group will establish a plan for development of validation criteria for experimental icing simulation facilities (tankers and tunnels) and icing simulation codes. The working group will develop level-of-acceptance criteria for validation comparisons. The group will examine correlation of ice shapes (including impingement) from icing facilities with those from flight in natural icing conditions. In addition, the group will examine correlation of ice shapes (including impingement) from ice accretion codes with those from both simulation facilities and natural conditions. The fidelity of artificial ice shapes needed to represent a natural event will be reviewed. Methods will be examined to provide quantifiable information on cloud characteristics, ice accretion shapes, and aero-performance measurements in natural icing to determine the comparison criteria for simulation. Methods for processing time-averaged flight data will be evaluated to support replicating natural icing events in ground-based facilities.

The working group also will address methods for defining tunnel/tanker cloud characteristics and their calibration and accuracy. This will include instrumentation employed in the establishment of those calibrations and methods to determine the facility's envelope. A set of equivalent icing conditions along with a standard model(s) will be identified for use in comparing icing simulation facilities. Means of comparison to cross reference individual facility results will be developed.

Issues related to the simulation of freezing drizzle, freezing rain, and mixed phase conditions either by a facility or a computer code also will be examined.

**Responsible Parties:** NASA LeRC, FAA Technical Center, and Aircraft Certification Service.

**Schedule:**

- August 1997: Develop interim recommendations on validation criteria.
- June 2001: Develop final recommendations on validation criteria.

**B. *VALIDATION DATA.* The FAA shall support research aimed at developing ice accretion data and associated aerodynamic effects that can be used for the validation of ice accretion codes and analysis of aerodynamic performance degradation due to icing. This research also can be used to form the basis of an evaluation of ice shape features resulting in critical performance loss.**

**<u>PLAN DETAILS, TASK 11.B.</u>:**

The NASA LeRC Modern Airfoils Ice Accretions Program receives funding support from the FAA. This program encompasses the development of ice accretions in icing tunnels on modern airfoils (2D) and wings (3D) of interest to industry and the FAA. It includes the acquisition of aerodynamic data using icing tunnel accretion models in high quality aerodynamic tunnels.

**Responsible Parties:** NASA LeRC, FAA Technical Center.

**Schedule:**

September 1998: Report on ice accretions for modern airfoils (2D), including $C_d$, $C_{l,max,}$ and stall angles.

**C. *SIMULATION IMPROVEMENT.* The FAA will support research on the development and improvement of ice simulation methods such as ice accretions codes, icing tunnels, and icing tankers. This research will be directed at understanding the physical processes underlying the ice accretion process, including phenomena associated with SLD ice accretion.**

**<u>PLAN DETAILS, TASK 11.C.</u>:**

A working group will be formed to publish a research plan that addresses how the FAA can most cost effectively improve the simulation capabilities of industry and research facilities.

**Responsible Parties:** FAA Technical Center, Aircraft Certification Service.

**Schedule:**

February 1998: Publish a Simulation Improvement Research Plan.